

# Towards 2010 NO<sub>x</sub> and PM emission Levels: Overview of CARB's Investigation of Advanced Heavy-duty On-road Vehicle Retrofits and Other Technologies

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## Introduction

The California PM emission standard for new heavy-duty engines was reduced from 0.1 g/bhp-hr to 0.01 g/bhp-hr in 2007. Similarly, the corresponding NO<sub>x</sub> emission standard will be reduced from last year's 2 g/bhp-hr to an eventual 0.2 bhp-hr limit in a stepwise fashion between 2007 and 2010. While diesel engine manufacturers have been able to meet previous emissions standards with engine design and combustion process improvements, the new very low emission limits will require nearly universal use of advanced aftertreatment. Some of these devices such as DPFs and SCR are currently being investigated in retrofit demonstrations. In the current work we present a project overview and preliminary results of criteria pollutants from several vehicles and aftertreatment devices evaluated at the California Air Resources Board's Heavy-duty Diesel Emissions Test Laboratory located in Los Angeles, CA. The project is a collaborative effort between investigators from CARB, USC, UCLA, UCD, and U. of Wisc.

## Overview and Goals

This project seeks to investigate the physicochemical and toxicological characteristics of exhaust emissions of in-use heavy- and light-duty motor vehicles projected to have significant share of the population and VMT in California. This study is a 4-year collaborative project focused on emerging issues of relevance for air quality and the protection of health. These issues include ultralow emissions from advanced aftertreatment technology, effect on emissions of ultrfine and nucleation mode particles by various aftertreatment devices, measurement instrumentation and protocols, and the relative toxicity of PM components as a function of volatility. The project builds on previous vehicle emissions research by CARB [1-4]. The premise for the study is the retrofit systems to today being a glimpse into the production-ready OEM systems of the future. With an eye toward 2010 emission standards, the project seeks to address the following:

**Hypothesis:** (a) Emerging, newer vehicle/engine systems will result in reduced emissions of physicochemical and toxicological relevance relative to existing, older systems.

(b) Toxicity is correlated with emissions of light / volatile PAH's

## Research Team



Co-sponsors:



Principal in-kind contributors:



## Experimental

Four heavy duty diesel vehicles in seven configurations were tested. The project also envisioned testing a 2010 compliant CNG bus, but none was available. Three cycles were tested, 50mph Cruise, UDDS, and Idle. Not all vehicles were tested on all three cycles. ULSD was used. Fuel and engine oil were collected for chemical analysis.



Veh#1 - Los Angeles Sanitation Transfer Truck. Tested in four different configurations.



Veh#2 - CalTrans Truck equipped with Engelhard DPX (Catalyzed DPF).



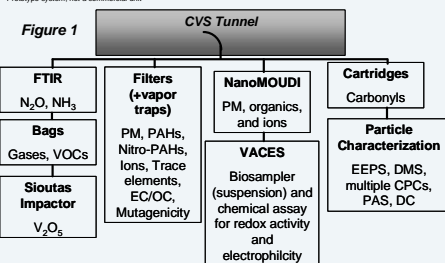
Veh#3 - Elk Grove School Bus, Retrofitted with a Cleaire Horizon electrically regenerated Trap.



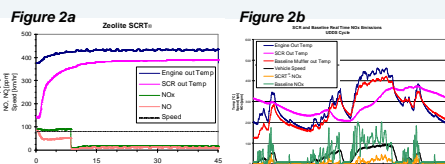
Veh#4 - Joquin RTD Diesel Hybrid Electric Bus with JM CCRT®. Cruise and Idle not tested.

Vehicle					Engine					Aftertreatment (AT)		
Vehicle Number	Make	Model	Year	Miles	Curb Weight (lb)	GVWR (lb)	Tested Wt (lb)	Model	Year	Size (L)	Rebuilt / Repower	Make and type
Veh#1, Baseline	Kenworth	T800B	1998	374000	26,640	80,000	53,320	Cummins M11, refashed	1998	11		none
Veh#1, CRT®	Kenworth	T800B	1998	374000	26,640	80,000	53,320	Cummins M11, refashed	1998	11		JM CRT®
Veh#1, V-SCRT®	Kenworth	T800B	1998	360000	26,640	80,000	53,320	Cummins M11, refashed	1998	11		JM SCRT®
Veh#1, Z-SCRT®	Kenworth	T800B	1998	360000	26,640	80,000	53,320	Cummins M11, refashed	1998	11		CRT + Zeolite SCR
Veh#2, DPX	International	4900	1999	40,000	15,030	27,500	20,920	International DT466E	1999	7.6		Engelhard DPX
Veh#3, Horizon	Thompson	SafetyLiner	1998	325000	22,200	36,200	26,720	Cummins	2003	5.9		Cleaire Horizon, EGR
Veh#4, CCRT®	Gillig (35th) with Allison Hybrid Drive		2007	1000	27,500	39,600	30,200	Cummins	2006	5.9		JM CCRT®
										Miles on AT		
										Description		
										0 on SCR, 50,000 on CRT		
										Uncatalyzed DPF		
										Catalyzed DPF		
										31,000		
										1000		

\* Prototype system, not a commercial unit



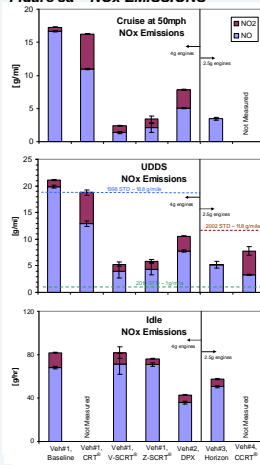
**Figure 1. Emission Characterization Scheme.** Sample collection of dilute exhaust from the CVS tunnel for physical, chemical, and toxicological characterization.



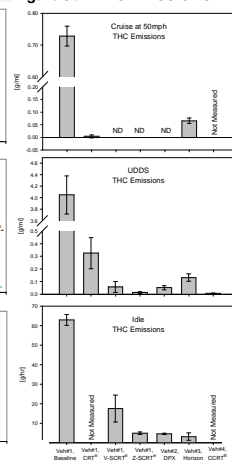
\* Prototype system, not a commercial unit

**SCRT®** **Figure 2. Real Time Performance of SCRT® during Cruise (2a) and Transient (2b) cycles.** SCR systems require minimum temperatures to operate properly. The SCRT® systems tested do not dose urea until this minimum temperature is reached. The cruise cycle shown in figure 2a was started after a hot soak and the initiation of urea injection is clearly visible approximately 8min into the cycle when NO<sub>x</sub> concentrations drop. The vehicle was warm at the start of the UDDS cycle shown in figure 2b and the SCRT® system was in operation during the entire cycle. Naturally, a delay similar to that seen in figure 2a occurs when the UDDS cycle is started cold. The delay in exposure and needs to be accounted for in inventories and exposure studies once these devices are in general use. The good news is that the SCRT® accomplished significant reductions once operational and the system remained at operational temperatures during the entire transient cycle.

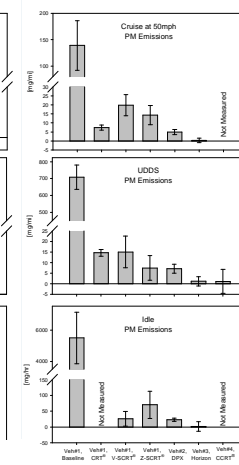
### Figure 3a - NO<sub>x</sub> EMISSIONS



### Figure 3b - THC EMISSIONS



### Figure 3c - PM EMISSIONS



## NO<sub>x</sub>, THC and PM Emissions

**Figure 3a. Average NO<sub>x</sub> and NO<sub>2</sub> Emissions.** NO<sub>x</sub> emissions from the seven configurations are dependent on engine size and model year, with the larger older engines emitting more NO<sub>x</sub>. The NO to NO<sub>2</sub> ratio is typically 10:1 in an unregulated engine but is affected by aftertreatment devices. The catalytic surface of the CRT®, Engelhard DPX and CCRT® is NO<sub>x</sub> neutral but increases the fraction of NO<sub>2</sub>. This assists in the regeneration of the traps. The Cleaire Horizon trap is uncatalyzed and also NO<sub>x</sub> neutral but increases the fraction of NO. The SCRT® systems reduced NO<sub>x</sub> emissions as compared to the base line by 92% and 87% during cruise and 80% and 78% during UDDS for the vanadium and zeolite systems respectively. However, in combination with the CRT®, during cruise, NO<sub>2</sub> emissions were increased even as overall NO<sub>x</sub> was decreased. During Idle the systems do not reach operating temperatures and have little to no effect.

**Figure 3b. Average Total Hydrocarbon Emissions.** The catalytic surfaces found in the CRT®, CCRT®, and DPX aftertreatment devices reduced THC emissions to near zero during the cruise cycles when all systems are hot and operating optimally. The systems also reduced THC by 90+ % for the UDDS cycle. Naturally, during the cold idle cycle reductions were much less. The uncatalyzed Horizon Trap was the highest emitter during the warmer cycles due to the lack of an oxidizing environment.

**Figure 3c. Average Particulate Matter Emissions.** Comparison of PM emissions of veh#1 with and without CRT® shows these traps to reduce emissions by 90+%. The newer engines in Veh#3 and Veh#4, when combined with wall-flow particle traps, are so clean that the gravimetric measurement is often below detection limits.

## Summary

The emission control devices tested all performed as expected, yielding PM, NO<sub>x</sub>, and THC reductions in accordance with their design and intent. Remaining issues include the temperature requirements of SCR systems and what that will mean for overall NO<sub>x</sub> reduction, and the effect of oxidation catalysts and catalyzed traps on NO<sub>2</sub> emissions.

## Next Steps

The testing of the heavy-duty vehicles is complete. We will proceed with chemical and data analysis and expect to begin reporting findings in peer-review literature in 2008. This will include findings on particle nucleation and toxicity. Also in 2008, the light-duty testing phase of the project will commence. Light duty technologies to be tested include CNG, E85, diesel, SULEV and an older vehicle.

## See also at AAAR

From the same project:  
**4D.2 Tuesday 2:15 pm: Nucleation Mode Particle Emissions from In-use Heavy Duty Vehicles Equipped with DPF and SCR Retrofits.**

**5D.4 Tuesday 4:35 pm: Physical Properties of Particulate Matter (PM) from Newer Heavy Duty Diesel Vehicles Operating with Advanced Emission Control Technologies.**

**11M.7 Thursday 9:15 am: Chemistry of Air Toxics Emitted from In-use Heavy Duty Vehicles Equipped with DPF and SCR Retrofits.**

## References

1. Ayala, A., N.Y. Kado, R.A. Okamoto, B.A. Holmén, P.A. Kuzmicki, R. Kobayashi, and K.E. Stiglitz (2002) "Diesel and CNG Heavy-duty Transit Bus Emissions over Multiple Driving Schedules: Regulated Pollutants and Project Overview," SAE Transactions Journal of Fuels and Lubricants, 735-747
2. Herner, J., A. Ayala, W.R. Robertson (2006) "Nanoparticle Formation in the Emissions from a Trap-Equipped Heavy Duty Diesel Truck" AAAR Conference Platform 12E4
3. J. Orin D. Herner, William Robertson, Alberto Ayala, and Constantinos Sioutas. (2007) Nanoparticles from a California in-use Heavy Truck Equipped with PM-NO<sub>x</sub> Retrofits. 11th ETH Conference on Combustion Generated Nanoparticles, 12-15 August 2007, Zurich.
4. CARB's Study of Emissions from In-Use CNG and Diesel Transit Buses: <http://www.arb.ca.gov/research/cng-diesel/cng-diesel.htm>

## Disclaimer

The statements and opinions expressed here are solely the authors' and do not represent the official position of the California Air Resources Board. The mention of trade names, products, and organizations does not constitute endorsement.